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Far-Infrared Heterodyne Receivers

Albert Betz

Space Sciences Laboratory, University of California
Berkeley, CA 94720

The development of open-resonator mixer structures and laser local oscillators has made heterodyne spectroscopy at far-infrared (FIR) wavelengths between $150\ \mu\text{m}$ and $400\ \mu\text{m}$ a reality. Several laser-based receivers are now part of the instrument complement flown aboard the Kuiper Airborne Observatory (KAO). Lasers are eminently practical as FIR local oscillators whenever there is close frequency coincidence ($<15\ \text{GHz}$) between a strong laser transition and the Doppler-shifted astronomical line. While it is of course desirable to have continuous frequency coverage in a spectrometer, it should be recognized that most astronomers will focus their interest on the few spectral lines deemed optimum for probing the cosmos. For example, at millimeter wavelengths almost twenty years after the first detection of interstellar CO, most observations still seem to be devoted to just the 1-0 and 2-1 lines of CO, even though complete frequency coverage is available. At FIR wavelengths, most of the more important spectral features, such as CI ($370\ \mu\text{m}$), CII ($158\ \mu\text{m}$), OI ($145\ \mu\text{m}$), and CO and H₂O (118 to $432\ \mu\text{m}$) have usable laser coincidences.

An example of a FIR heterodyne spectrometer designed for airborne astronomy is the UCB instrument illustrated schematically in FIGURE 1. The receiver consists of a corner

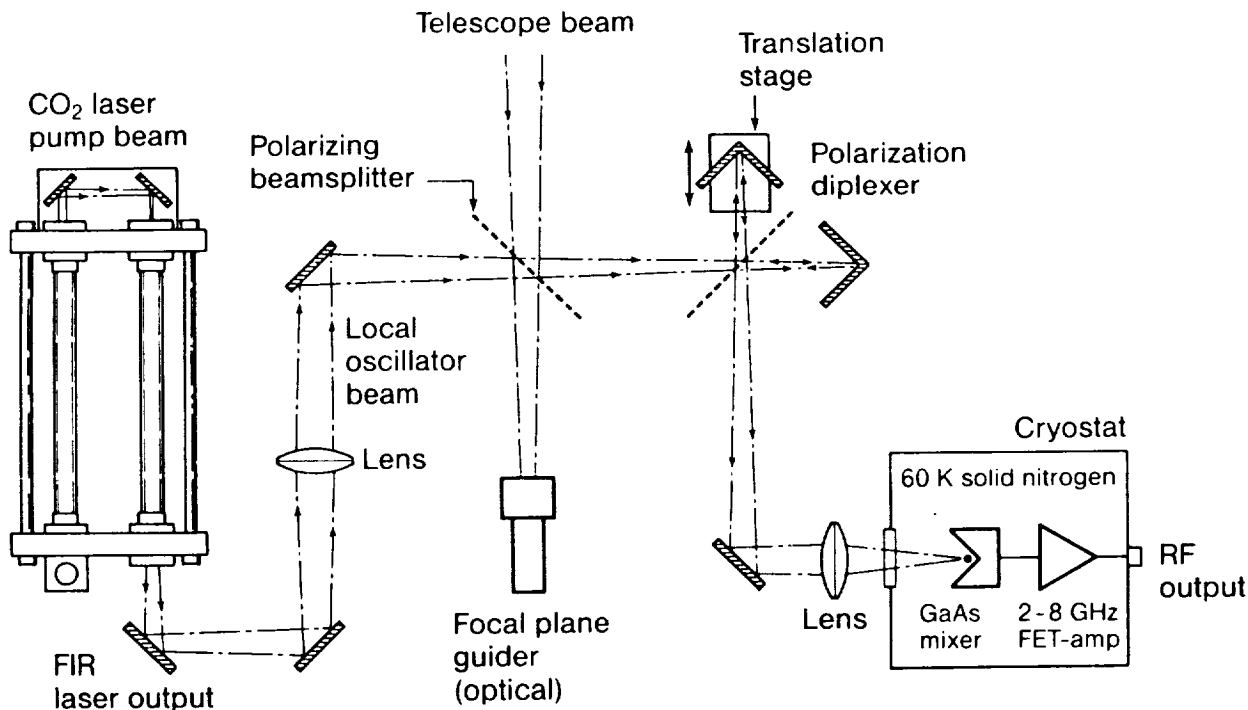


FIGURE 1. Airborne Far-Infrared Heterodyne Spectrometer

reflector mixer and a 1-m FIR laser-LO pumped optically by a 10 W CO₂ laser. The entire system has a mass of 100 kg contained in a volume of 1.4 x 0.4 x 0.4 m³. The spectrometer has flown on the KAO over the past three years and produced a number of unique observations of line emission from neutral and ionized carbon in the interstellar medium. FIGURE 2 shows representative spectra of the CI (800 GHz) and CII (1900 GHz) lines in the Orion Molecular Cloud (OMC) at resolutions of 1.8 and 0.8 km/s, respectively.

Observations at wavelengths as short as 100 μ m (3000 GHz) require careful attention to mixer design, because some dimensions must be maintained with a tolerance of about 10 μ m. Heretofore, the standard design for a corner reflector mixer has a 4- λ whisker-antenna spaced 1.2 λ from the vertex of a 90° corner reflector. At short wavelengths, difficulties in fabricating a 4- λ antenna accurately make it desirable to use a longer antenna and a larger vertex spacing. In general, the optimum position of the antenna is at the peak of the standing-wave distribution of the electric field induced inside the reflector by a plane wave incident at the main-lobe angle of the long-wire antenna. This spacing is easily calculated for any

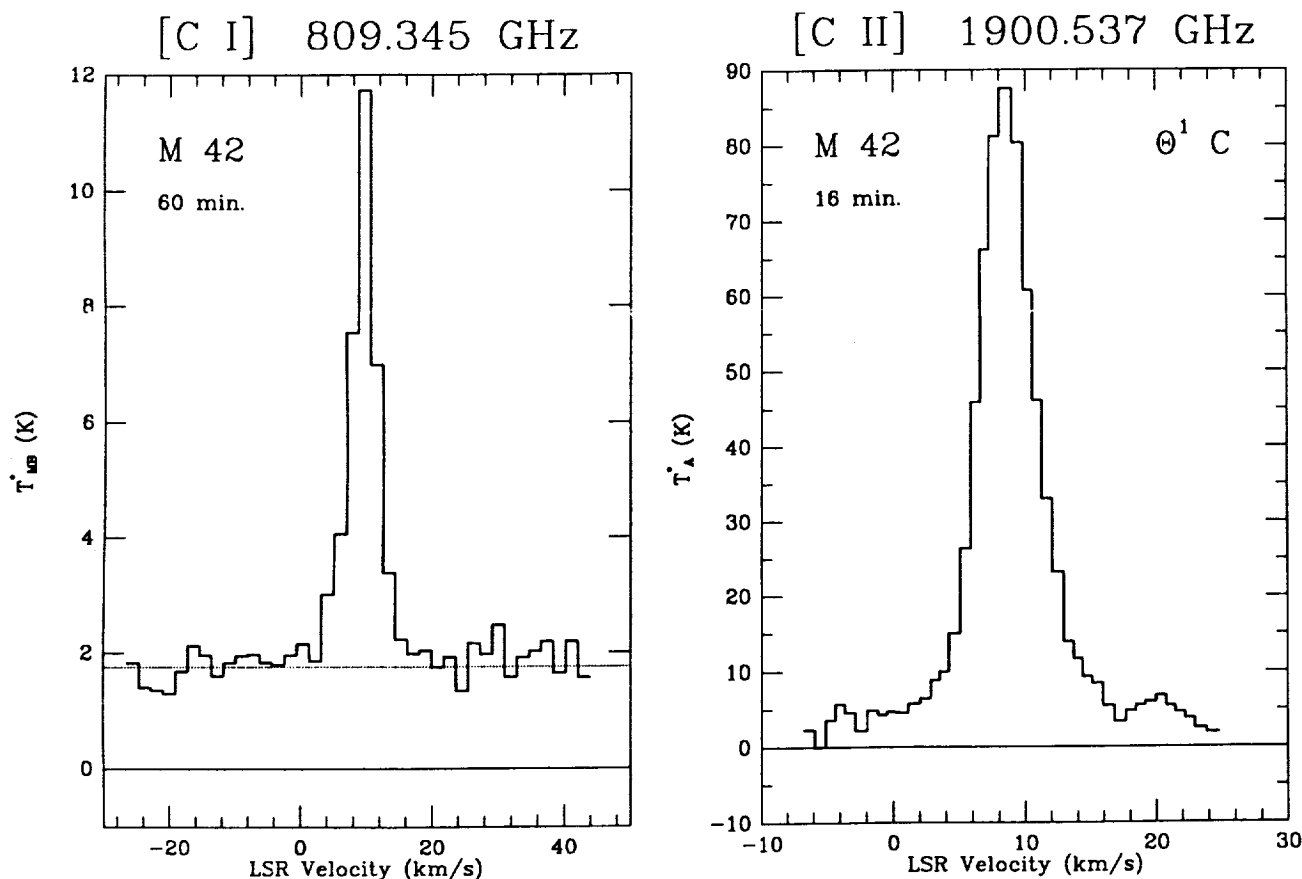


FIGURE 2. Representative spectra of CI and CII in the OMC

antenna length L from the relationship: $s = \lambda/2 \sin(\theta)$, where the main lobe angle is given by: $\theta = \arccos(1 - 0.371 \lambda/L)$. Antenna patterns calculated with whisker lengths between 4 and 10 λ give approximately symmetric main lobes with widths ranging from 14 to 8 degrees, and agree with our laboratory measurements.

The immature development of our FIR mixer technology is apparent from the somewhat high noise temperatures of 8000 K and 28000 K (SSB) achieved in observations at 809 and 1900 GHz, respectively. These sensitivities, although quite usable, are about 200 times worse than the quantum-noise limit, but will certainly improve in the near future. Recent advances in the fabrication of GaAs diodes optimized for short wavelengths should lead to a steady reduction in noise temperatures similar to that experienced with millimeter-wave mixers during their first decade of development. Although conventional SIS-type mixers may appear to offer strong competition at the longer wavelengths, the GaAs devices have cooling requirements more amenable to space applications. Regardless, for the next few years the advantage in fieldable systems seems likely to remain the Schottky technology. Ultimately, the development of a reliable thin-film technology for the new high-temperature oxide superconductors may favor SIS-type devices for all wavelengths in future space-based FIR receivers.